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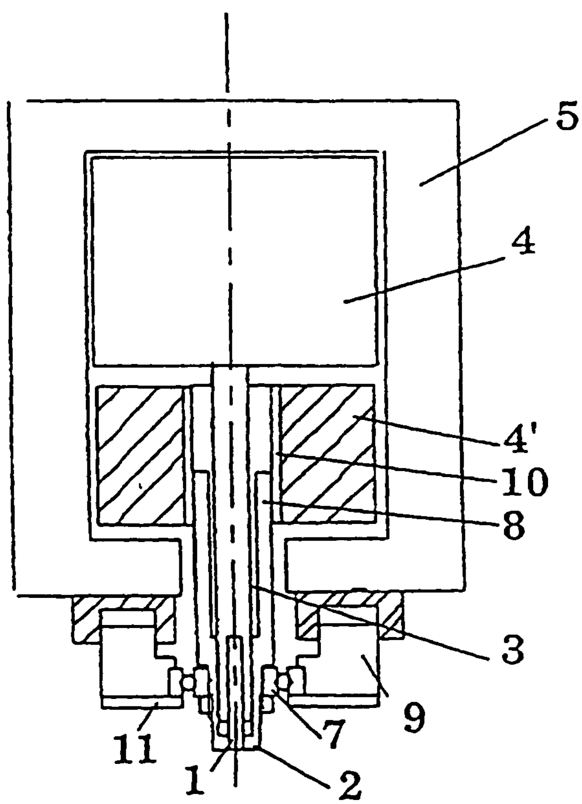
(54) Title: FRICTION STIR SPOT WELDING METHOD AND APPARATUS



(57) Abstract: Modified method for friction stir welding process where the shoulder (2) being independently movable of the pin (1) exercises controlled and variable forces on the assembled joined-to-be members so that the down force under retraction of the pin exceeds the plasticity limit of excess material collected under the shoulder.

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— *With international search report.*
— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

"Fricition stir spot welding method and apparatus"

The present invention relates to a new improved method of friction stir welding of members, more particularly to a spot welding method, and furthermore to apparatuses to conduct such method.

Friction stir welding is a new friction welding process representing a disruptive welding technology. The principles of the process and applied apparatus disclosed by WO93/10935 are based on a relative cyclic movement between a non-consumable probe of a harder material than the workpieces to be joined and the workpieces. Urging the rotating probe into the assembled adjacent workpieces along their joining line creates a plasticized region in the workpieces due to a generated frictional heat. Thus no heat is generated as in conventional friction stir welding due to a relative motion between the workpieces to be joined. This new welding method, having the advantage of solid state bonding, has been successfully implemented on providing plate and profile seam joints not previously feasible and gains increasing popularity for numerous joining applications.

However, provision of so-called keyholes resulting from retraction of the probe by termination of the welding requiring normally removal of such inadequately filled part of the seam weld represents certain limitations to even broader applications.

Thus, e.g. in spot welding processes being presently extensively applied in robotazing of assembling operations in vehicle building (welding of steel sheets to the supporting structure of the vehicle body), the use of aluminium as sheet material has so far been eliminated due to the low strength joints resulting from classical Al-welding methods (TIG, MIG).

Drawbacks linked to the presently known/applied friction stir welding apparatuses - large down load forces on the welded members and presence of keyholes - have so far eliminated possible application of friction stir welding technology in this field.

It is therefore an object of the present invention to provide a novel improved method of friction stir welding providing a weld avoiding the above difficulties connected to the existence of the keyholes.

Another object of the present invention is to provide improved modifications of friction stir welding apparatuses ensuring a substantial keyhole filling during/after the probe's retraction from the joined members.

These and other objects are met by provision of a novel modified friction stir welding method and novel apparatus as defined in the attached patent claims 1 and 4, respectively.

Other objects, specific features and advantages of the present invention will become apparent from the following detailed description of the preferred embodiments of the apparatus and the mode of operation according to the invention with reference to the accompanying drawings, Figs. 1-3, where

Fig. 1 illustrates schematically the novel principle of the improved friction stir welding by means of controlled and variable forces (exercised in the joined-to-be members).

Fig. 2 shows schematically in a vertical cross-sectional view a construction principle of the applicable friction stir welding apparatus.

Fig. 3 shows schematically in a vertical cross-sectional view another variant of the friction stir welding apparatus.

The friction stir welding as described in WO93/10935 is incorporated herein by reference to the extent consistent with the present invention.

Referring to Fig. 1, the principle of the novel friction stir welding based on a shoulder being movable independently of the pin and exercising controlled and variable (down) forces on the pre-assembled joined-to-be members is illustrated schematically as steps 1a-1e in the basic welding cycle.

A motor driven rotating cylindrical pin 1 is mounted in a rotating cylindrical shoulder 2 with the pin being movable along their combined central axis (from hereon denominated z-axis) independently of the shoulder during the welding cycle. The movement of the pin along the z-axis is controlled by an actuator (not shown in the Figure), the actuator being e.g. a milling machine, friction stir welding machine, arm of a welding robot, a hand held machine or any other applicable means. The movement of the shoulder along the z-axis is force controlled during the welding cycle. The shoulder's z-axis rotation velocity and direction can be chosen independently from the pin or be identical. An extra containment shoulder 21 encompassing the shoulder 2 independent of said shoulder's z-axis rotation can be an option to aid refilling of the keyhole. The pin itself can be either smooth, have a modified surface, or have a reverse pitch with regard to its direction of rotation; thus further enhancing the refilling of the keyhole.

The basic welding cycle contains the following steps as shown in Figure 1:

Step a: Initial contact

The rotating pin 1 is brought in contact with the to be welded members A,B, and a positive down force F1 is applied on the shoulder to get it in contact with the to be welded members. The pressure exerted by the shoulder is chosen to be less than the yield strength of the to be welded material. The shoulder can optionally rotate to give additional heat input to aid the plasticizing process.

Step b: Penetration

While the down force F1 on the shoulder is maintained (or eventually reduced), the rotating pin is moved into the to be welded components. Optionally an extra containment shoulder 21, shown schematically co-axially arranged to and enveloping the shoulder 2, is lowered down to the surfaces of members A,B. The function of the containment shoulder 21 is to keep the excessive upcoming material under the shoulder 2 also during the following steps c and d.

Step c: Initial welding

While the down force F1 on the shoulder is maintained (or eventually reduced), penetration of the pin continues until the full penetration depth has been reached. In this step initial solid state bonding between the two components takes place. The material displaced by the pin is in this step moved upwards and collects under the shoulder, while the relative (vertical) position of the shoulder is dependent on/adapted to the actual amount/volume of the displaced material by the pin 1.

Step d: Retracting

While the pin is retracted, the down force on the shoulder F1 is increased to such an extent that the plasticity limits of the excessive material under the shoulder is exceeded. This will lead to back extrusion of excessive material along the perimeter of the pin into the gap occurring under the pin while retracting. This back extruded material is integrally bonded in the gap under the pin due to the deformation exerted on it by the rotating pin, effectively leaving a plugged up hole containing solid state bonded material when the retraction is complete. Thus the welding operation is accomplished without any lateral translation movement of the shoulder.

Step e illustrates the completion of the welding cycle showing substantially reduced volume of the hole 10 by a simple "plunge/lift" operation of the tool keeping the shoulder under down force.

Figure 2 illustrates in a cross-sectional view the apparatus for making friction stir welds with force controlled shoulder and friction stir welded spot welds in a simple form, having the shoulder 2 and pin 1 rotating at the same rotational velocity. The apparatus can also make shoulder down force controlled butt welds.

This "automatic" positioning of the shoulder on the surfaces of the joined-to-be members is possible due to the fact that no special positioning means are applied/ necessary according to the novel inventive construction principle of the tool.

The apparatus comprises conventionally a frame 5 that is mountable at the end of e.g. a robot arm (not shown in the Figure), milling machine, friction stir welding machine or any other applicable means. A hand held variant might also be viable. In the frame 5 power source, e.g. a motor 4, is mounted which axle is driving a tool holder 3. The friction stir weld pin, either with or without reversed thread pitch is fixed, thus rotating at motor speed. The shoulder 2 is constructed in such a manner that it has a loose splined fit with tool holder 3 and pin 1 and therefore can slide along the z-axis over the tool holder, while the rotational velocity of the shoulder is identical to that of tool holder and pin. Other means for restriction of the rotational freedom, e.g. a keyway solution, are also applicable. The shoulder is mounted inside an axial truss bearing 7 which is mounted in a hollow piston 9, the piston being part of a hollow hydraulic or pneumatic actuator, thus ensuring the down force control over the shoulder. Other means of actuation are conceivable/applicable.

An alternative construction apparatus having independently rotating pin and shoulder is shown in Figure 3.

In this case the frame 5 contains two motors, the top motor 4 having an axle going through the hollow axle of the bottom motor 4' and driving the tool holder 3 through an extension. The shoulder extension in itself forms a hollow axis 8 and can slide in the hollow motor axle 10 with a loose splined fit. The shoulder z-axis rotational

degree of freedom is now constricted, effectively making the shoulder rotate with the same velocity as the hollow axle of the bottom motor. Only loose fit between shoulder and tool holder is now present, thus ensuring additionally z-axis rotational degree of freedom between these two. The constraining shoulder can typically for both principles be spring loaded and attached to the cover plate 11 of the piston.

An obvious advantage of the independently rotating pin and shoulder is to separate function of heat input from the shoulder and the induced deformation by the pin rotation, which are both a function of their rotational velocity. This means more flexibility and better control with regard to the welding process parameters. Furthermore, the automatic positioning of the shoulder on the welded members will also cope with the thickness variations in the weld members ensuring uniform seam welds of improved quality when applied on butt welded members.

Other technical solutions to obtain independent z-axis rotational direction and velocity between pin and shoulder are possible within the scope of the invention.

Claims

1. Welding method for spot joining of assembled members, c h a r a c t e r i z e d i n t h a t the welding is conducted by a friction stir welding process applying shoulder and rotating pin where the shoulder is movable independently of the pin and exercises controlled predetermined and variable forces on the assembled joined-to-be members, wherein the down force on the shoulder under retraction of the pin exceeds the plasticity limit of excessive welded material collected under the shoulder, thereby forcing thus plasticized material downward under retraction of the pin.

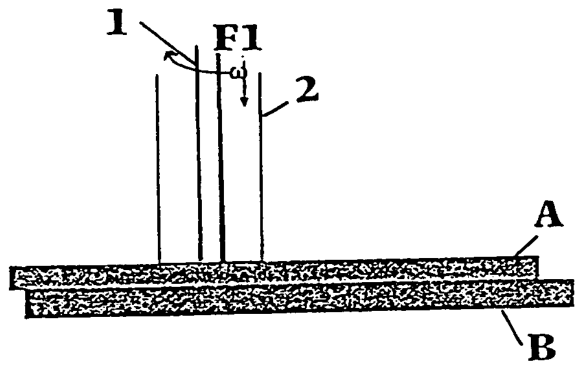
2. Welding method according to claim 1, c h a r a c t e r i z e d i n t h a t the shoulder and the pin rotate independently of each other.

3. Welding method according to claim 1 or 2, c h a r a c t e r i z e d i n t h a t the flow of the plasticized material is additionally controlled by the pin surface configuration adapted for reverse flow and compacting of the plasticized material.

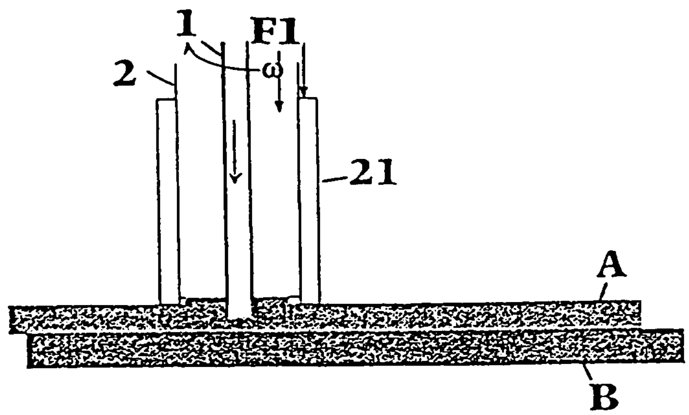
4. Modified apparatus for friction stir welding comprising a shoulder (2) and rotating pin (1), the shoulder being provided with means (9) to exercise controlled and variable down forces F1 on the assembled joined-to-be members (A,B).

5. Apparatus according to claim 1, c h a r a c t e r i z e d i n t h a t the pin (1) and the shoulder (2) are provided with separate power sources (4,4') ensuring their independent rotation.

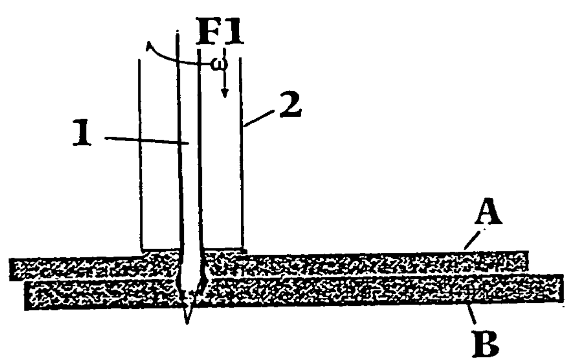
6. Apparatus according to claim 5 or 6,
c h a r a c t e r i z e d i n t h a t
a containment shoulder (21) is co-axially arranged enveloping the shoulder (2).



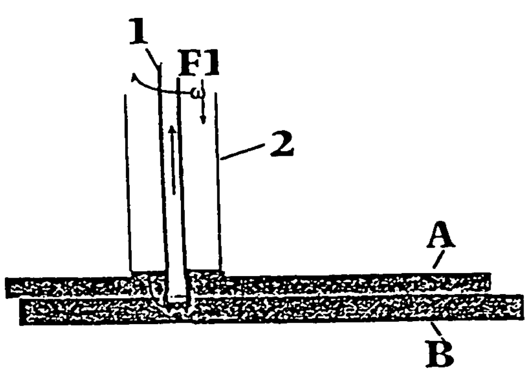
Step a



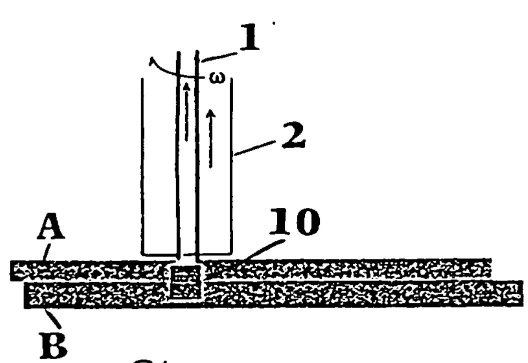
Step b



Step c



Step d



Step e

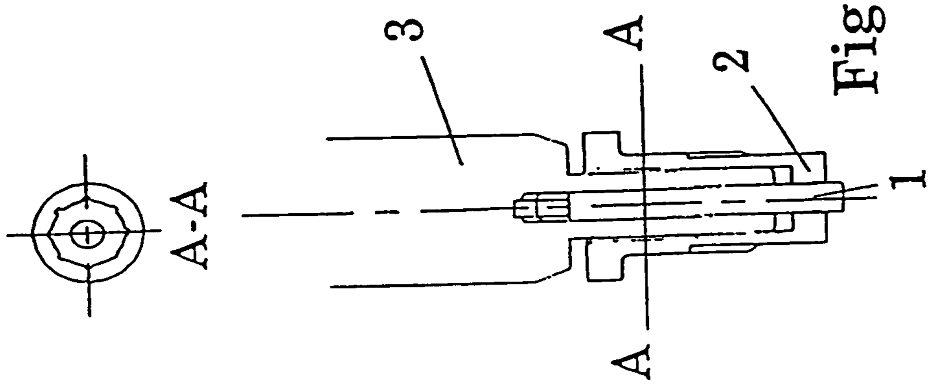


Fig. 2a

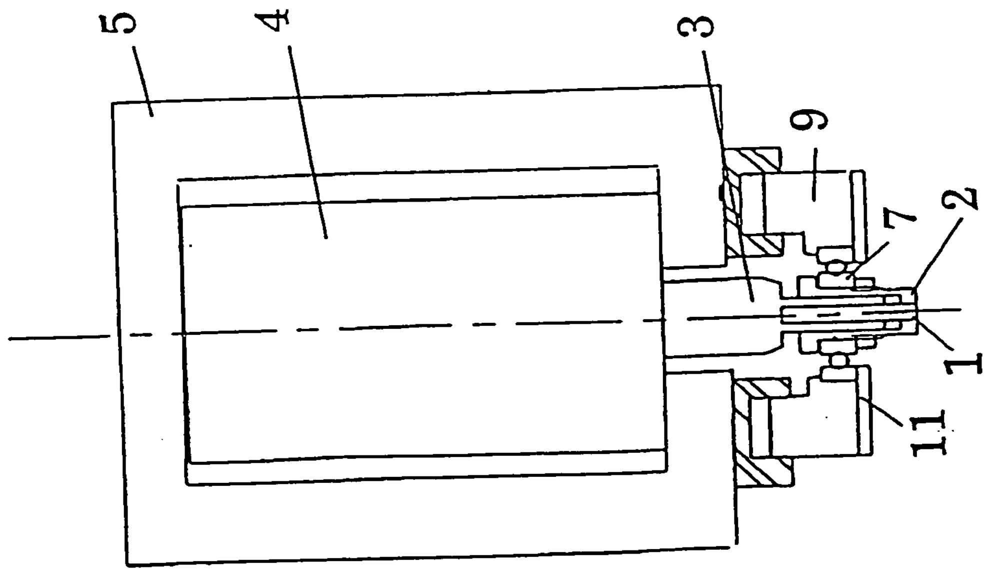


Fig. 2

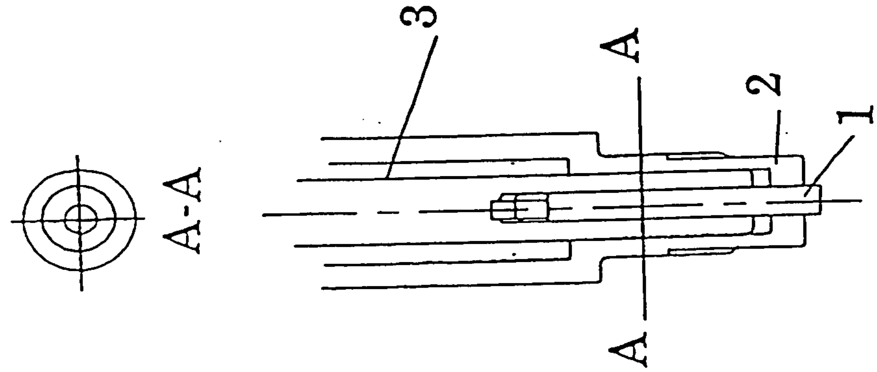


Fig. 3a

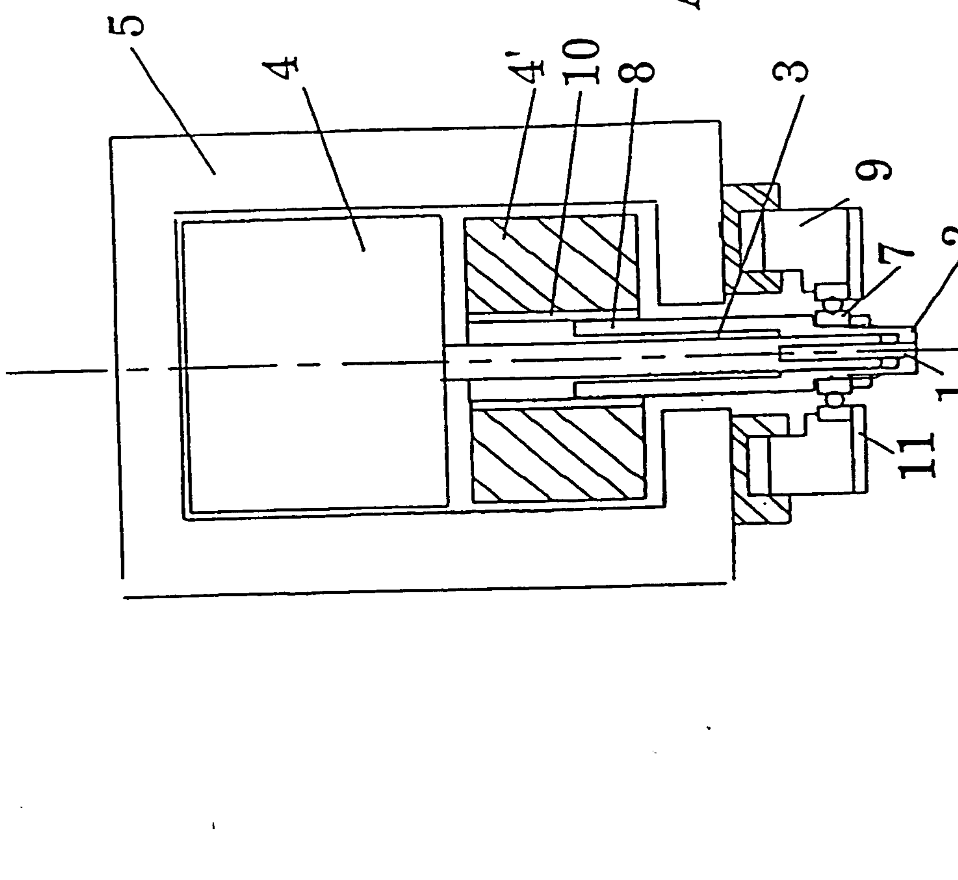


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 00/00344

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: B23K 20/12
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0867254 A1 (SHOWA ALUMINIUM CORPORATION), 30 Sept 1998 (30.09.98), figure 1, claim 1	4
A	abstract	1-3,5-6
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A	DE 19630271 A1 (B.SUTHOFF ET AL.), 23 April 1998 (23.04.98), abstract	1-6
	--	
A	WO 9310935 A1 (THE WELDING INSTITUTE), 10 June 1993 (10.06.93), abstract	1-6
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2001	15-02-2001
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Mats Raidla/LR Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

27/12/00

International application No.
PCT/NO 00/00344

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